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Early ontogenesis of the Yezo scallop, Patinopecten yessoensis (Jay):
quantitative characteristics of metabolism in a laboratory culture

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Early ontogenesis of the Yezo scallop, *Patinopecten yessoensis* (Jay): quantitative characteristics of

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metabolism in a laboratory culture

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by L.G. Makarova, Yu.E. Bregman, G.M. Guyda and
G.I. Viktorovskaya (TINRO**)

Commercial exploitation of the bivalve mollusk Patinopecten yessoensis in southern Primor'ye*** has been going on since 1919, when the diving method of harvesting them was first used. By 1920, the catches had reached 12,000*centners, but they did not continue to increase, due to the limited nature of the natural stocks of this mollusk (Skarlato, 1981). The scallop industry was closed in 1962, and scientists began to develop the biological foundations of scallop cultivation under the conditions of Primor'ye. In addition to the available data on the distribution, stock and rates of growth (Razin, 1934; Bazikalova, 1934), an abundance of data was collected on the population dynamics, mortality and growth rates of the larvae in the plankton and of the spat on the collectors and in the cages, as well as on the temperatures of growth, the characteristics of gametogenesis, metabolism and growth, the structure of a population, etc. (Golikov, Skarlato, 1969; Bregman, 1971, 1973, 1979; Dzyuba, 1972;

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*The numbers in the right-hand margin are the pages of the Russian text; **Pacific Ocean Scientific Research Institute of Fisheries and Oceanography; ***the "Maritime Province" of the Pacific coast of the USSR — transl.

* Centner — a unit used in the USSR, equal to 220.46 pounds: metric centner (Webster's)



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Logvinenko et al., 1982; Belogradov et al., 1977; Tibilova, Bregman, 1975, etc.), which have served as the basis for the development of the necessary technical documentation and the establishment of the first marine establishment for the cultivation of scallops (in Pos'yey Bay in 1971). Today, there are two more of these scallop farms, in Slavyanka Bay and on Popova Is. The output of the three scallop farms in 1984 amounted to about 30 tons (fresh weight).

The expansion of scallop plantations is being held back mainly by factors of an organizational and material-technical nature, as well as by the instability of the spat harvests. During unproductive years (e.g. in 1978 and 1980), the number of larvae in the plankton and the density of spat on the collectors decrease manifold. Because of this, we had to develop methods of obtaining hardy scallop spat in a fully controlled environment. Such methods are being used more and more extensively for obtaining the spat of oysters, clams and other mollusks for commercial and scientific purposes in the USA, Great Britain and Canada (Walne, 1979).

Papers devoted to the early ontogenesis of the Yezo scallop are not numerous (Yamamoto, 1966; Takeo, 1967; Sanders, 1973; Mileikovsky, 1980); as a rule, they deal mainly with a specific experiment restricted to the production and cultivation of larvae and the morphometric characteristics of the individual stages. At the same time, we have no information about the quantitative characteristics of its metabolism at the early stages of biological development, though without this information it is impossible

(12)

to obtain scientifically based standards for the maintenance of larvae and spat.

This particular paper deals with the main physiological processes of the scallop at the juvenile stages, and it has enabled us to develop tentative standards for feed concentration, the rate of supplying feed, oxygen conditions and the density of stocking.

Material and method. The investigations were carried out during May—July 1983 and 1984 at the TINRO experimental station (Popova Is.). Third- and fourth-year scallops at the spawning stage were caught in the sea, and after a one-week adaptation period were induced to spawn by means of a gradual increase in water temperature from 7-9 to 15°C. After fertilization, egg cells washed by decantation (density 200 egg cells per ml) were placed in glass 20-litre cylinders containing water filtered through a sand-gravel filter and sterilized by ultraviolet rays, where they developed up to the trochophore stage. The trochophores that collected in the surface film were siphoned off into other vessels (density 50 specimens/ml). From then on, the larvae were fed daily, yellow-green microalgae of the species Pavlova lutheri (cell diameter 2-3 µm) for the first ten days, with the addition of green microalgae of the species Platimonas viridis (10-12 µm) after that. The water and vessels were changed every 2-3 days, and the temperature was maintained at 15±0.5°C.

The feed was grown at 24-28°C by letting it accumulate on Goldberg medium (Kabanova's modification) with the use of intensive aeration and light from ~~API~~-700 lamps. One-half of the medium was replaced with fresh medium every week. The

density of larval stocking was gradually reduced from 5 veliger larvae to one veliconch per ml.

We performed two experiments on prolonged cultivation of larvae. The data of one of these experiments were used to determine the survival rate of the larva at different stages of development, and the data of the second experiment to study metabolism.

The survival rate was determined in the main embryonic and larval stages from the number of fertilized egg cells.

Shell length was measured every 5-7 days to determine the linear growth rate; the mean values were used to calculate the absolute $(dL/dt = (L_2 - L_1)/(t_2 - t_1))$ and relative rates $(dL/dt \cdot 1/L = (\ln L_2 - \ln L_1)/(t_2 - t_1))$ of linear growth. The empirical dependence of larval size on larval age was approximated by a single function (exponential curve) which was used to calculate the mean theoretical values of shell length and body mass for each 48-hour interval (Chislenko, 1968). (13)

The energy equivalents of the microalgae and larvae were determined by wet combustion (Recommendations Re the Determination...., 1983). First, the algae were separated from the medium by centrifuging, and 1 ml of suspension with a given number of cells was subjected to combustion (11 and 13 replications); the larvae were strained on membrane filters (pore diameter 4 μm) covered with a layer of powdered glass, and then placed with the latter in test tubes for combustion (10 replications for larvae measuring 200-205 μm in length). The content of carbon was recalculated to calories (1 μg of organic carbon equivalent to $10.08 \cdot 10^{-3}$ cal).

The rations (C) were calculated by the formula

$$C = (P + R)/u^{-1},$$

where P denotes the increase in body mass, R the mean metabolic expenditure of one larva for a 48-hour period, and u^{-1} assimilability which is accepted as 0.9.

The rate of filtration (F) was defined as the ratio $C/\bar{q}$, where $\bar{q}$ denotes the average content of food particles (SOM - suspended organic matter) measuring over $0.4 \mu m$ ($\bar{q}=1.52 \pm 0.22 \text{ cal} \cdot l^{-1}$) in the medium.

The rates of filtration and the rations of the larvae, namely 6-day-old veliger larvae, were also determined directly, by the rate at which the food was eliminated. Two experiments were performed at a temperature of $15^{\circ}C$ (each in 5 replications), the first experiment with an initial concentration of $K_0=20.8 \cdot 10^4$ cells, and the second experiment with $K_0=29.2 \cdot 10^4$ cells of P. lutheri per ml (2.29 and $3.21 \text{ cal} \cdot l^{-1}$ respectively). The natural sedimentation of feed was recorded in the control vessels.

The metabolism of the larvae was judged by the rate of oxygen consumption (Q), which was measured in fertilized egg cells, veliger larvae of different size and spat at a temperature of $15^{\circ}C$ by the method of closed vessels* (Winkler's micromethod). From 3 (in the case of spat) to 100 larvae and from 2060 to 4130 egg cells were placed in each 15.5-18.13 ml chamber. Exposure time was 24 hours. During this period, the decrease in oxygen content in the experimental vessels did not exceed 20% of the initial level. The rate of oxygen consumption was expressed in $mgO_2 \cdot h^{-1} \cdot \text{specimen}^{-1}$, and the amount of consumed oxygen in calories multi-

(14)

*translated literally - transl.

plied by the oxygen-calorie coefficient ($3.41 \text{ cal} \cdot \text{mg}^{-1} \text{O}_2$).

Having calculated Q from body mass (W, mg), we were also able to estimate the mean metabolic expenditure for 48-hour intervals of a theoretical curve of mass increment.

Empirical data and approximation. The scallop developed rapidly at a temperature of 15°C , i.e. the embryos became mobile after 24 hours, and the veliger larvae began to feed and their stomachs turned green after 48 hours. The larval period lasted for about 1 month, and it took another 40 days for the spat to reach a 1 mm size. The highest mortality was noted primarily during internal reorganizations and changes in the mode of life, i.e. during the transition from veliconch to spat (metamorphosis) and from developed veliger larva to veliconch (development of a foot and a prodissoconch II). The total yield of hardy spat amounted to 1% of the number of fertilized egg cells (table 1).

Development and survival rate of the Yezo scallop at the early stages of ontogenesis (15°)

Stage of development	Age from the time of fertilization, h	Survival, %
Polar body		
first	1.2	90 ± 0.3
second	1.6	86 ± 0.2
Blastomeres		
two	1.9	83 ± 0.2
four	3.1	82 ± 0.3
eight	4.0	81 ± 0.3
sixteen	7.3	80 ± 0.3
Blastula	15.0	80 ± 0.2
Mobile embryo	25.0	79 ± 0.2
Trochophore	35.0	74 ± 0.3
Early veliger	48.0	68 ± 0.3
Veliger larva	96.0	51 ± 0.2
Veliconch	295.0	22 ± 0.2
Spat	720.0	2 ± 0.1
Hardy spat	1680.0	1 ± 0.1

The shell length of the larvae and spat (L , μm) is exponentially dependent on their age (t , days) (fig. 1).

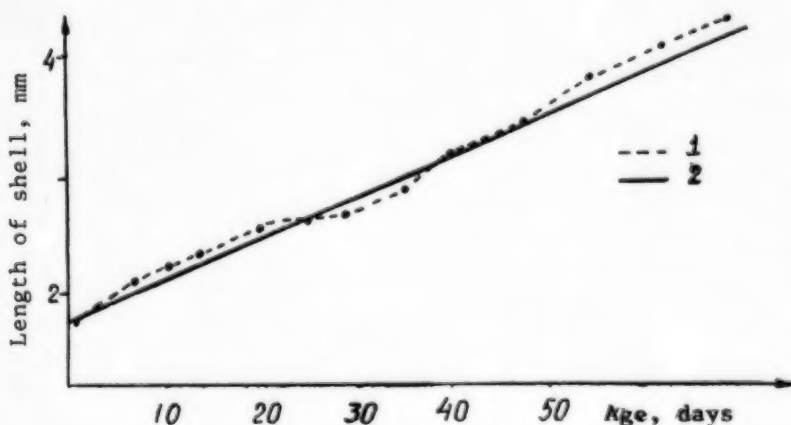


Fig. 1. Linear growth of *Patinopecten yessoensis* larvae and spat (semilogarithmic scale): 1 - empirical curve plotted from the mean values of size; 2 - theoretical growth curve

(15)

$$L = (81.1 \pm 1.01) e^{(0.039 \pm 0.002)} \quad (1)$$

$N = 370$ measurements, $r = 0.959$

The initial material is approximated even better by two different functions, i.e.

$$\text{for the larval period } L = 97.5 e^{0.028} \quad (2)$$

$N = 195$, $r = 0.990$

$$\text{for spat } L = 51.1 e^{0.048} \quad (3)$$

$N = 209$, $r = 0.004$

The exponential type of growth in juvenile scallops is confirmed by the constancy of its specific rate.

The growing scallop larvae retain a geometrical likeness of the body, and so the height of the shell (h , μm) is directly proportional to the length (μm), i.e.

(16)

$$h = /0.613 \pm 0.004 / L^{1.07 \pm 0.01} \quad (4)$$

$N = 59$, $r = 0.999$,

while the exponent in the equation of the relationship between live body mass W (mg) and length L (mm) approximates three, i.e.

$$W = (0.121 \pm 0.008) L^{2.9 \pm 0.04} \quad (5)$$

$N = 50, r = 0.006$

According to equations (1) and (5), the body mass and age of the larvae are correlated in the following way:

$$W = 8.33 \cdot 10^{-5} e^{0.113t} \quad (6)$$

The rate of oxygen consumption Q ($\text{mgO}_2 \cdot \text{h}^{-1} \cdot \text{specimen}^{-1}$) by the larvae and spat depends on their body mass W (mg), i.e.

$$Q = (0.164 \pm 0.012) \cdot 10^{-2} W^{0.667 \pm 0.039} \quad (7)$$

$N = 32, r = 0.953$

The average calorie value of the larvae amounted to 0.9 ± 0.2 cal per mg of live mass, while that of 10^6 cells of P. lutheri and Pl. viridis was 0.011 ± 0.002 and 0.541 ± 0.016 cal respectively. Elements of the energy balance (table 2) of the scallop larvae and spat developing in accordance with equation (1) enabled us to calculate the required ration C ($\text{cal} \cdot \text{specimen}^{-1} \cdot \text{day}^{-1}$) and filtration rate F ($\text{l} \cdot \text{h}^{-1} \cdot \text{specimen}^{-1}$) for each 48-hour interval. These indices depend on body mass (W , mg):

$$C = (0.213 \pm 0.002) W^{0.708 \pm 0.005} \quad (8)$$

$N = 23, r = 0.999$

$$F = (0.586 \pm 0.006) \cdot 10^{-2} W^{0.707 \pm 0.005} \quad (9)$$

$N = 23, r = 0.999$

According to the results of direct calculation, the ration was equal to $(8.5 \pm 3.17) \cdot 10^{-4}$ and the rate of filtration to $(0.21 \pm 0.1) \cdot 10^{-4} \text{ l} \cdot \text{h}^{-1} \cdot \text{specimen}^{-1}$ in veliger larvae with the concentration of P. lutheri at $20.8 \cdot 10^4 \text{ cells} \cdot \text{ml}^{-1}$ ($2.29 \text{ cal} \cdot \text{l}^{-1}$); the rate of filtration remained the same, but the ration increased

to $(12.8 \pm 1.35) \cdot 10^{-4} \text{ cal} \cdot \text{day}^{-1} \cdot \text{specimen}^{-1}$ with a concentration of $29 \cdot 10^4 (3.21 \text{ cal} \cdot \text{l}^{-1})$. These values correspond quite well with the data in table 2, i.e. $C = 4.7 \cdot 10^{-4} \text{ cal} \cdot \text{day}^{-1} \cdot \text{specimen}^{-1}$ and $F = \frac{4.7 \cdot 10^{-4}}{1.52 \cdot 24} = 0.13 \cdot 10^{-4} \text{ l} \cdot \text{h}^{-1} \cdot \text{specimen}^{-1}$, considering that higher concentrations of feed were used in the experiment.

Table 2. Elements of energy balance in P. yessoensis at the early stages of ontogenesis

Stage of development and age, days	Average length, mm	Average mass, kg	Increment, cal · specimen ⁻¹ · day ⁻¹	Metabolic expenditure, cal · specimen ⁻¹ · day ⁻¹	Ration, cal · day ⁻¹ · specimen ⁻¹
Veliger larvae					
2-4	0,092	$1,18 \cdot 10^{-4}$	$1,18 \cdot 10^{-5}$	$3,22 \cdot 10^{-4}$	$3,71 \cdot 10^{-4}$
5-7	0,103	$1,67 \cdot 10^{-4}$	$1,71 \cdot 10^{-5}$	$4,06 \cdot 10^{-4}$	$4,70 \cdot 10^{-4}$
8-10	0,116	$2,39 \cdot 10^{-4}$	$2,39 \cdot 10^{-5}$	$5,10 \cdot 10^{-4}$	$5,93 \cdot 10^{-4}$
11-13	0,130	$3,27 \cdot 10^{-4}$	$3,29 \cdot 10^{-5}$	$6,35 \cdot 10^{-4}$	$7,42 \cdot 10^{-4}$
Veliculus					
14-16	0,146	$4,58 \cdot 10^{-4}$	$4,45 \cdot 10^{-5}$	$7,96 \cdot 10^{-4}$	$9,33 \cdot 10^{-4}$
Umbonal stage					
17-19	0,164	$6,42 \cdot 10^{-4}$	$6,62 \cdot 10^{-5}$	$9,98 \cdot 10^{-4}$	$1,18 \cdot 10^{-3}$
20-22	0,184	$8,96 \cdot 10^{-4}$	$8,91 \cdot 10^{-5}$	$1,24 \cdot 10^{-3}$	$1,48 \cdot 10^{-3}$
Pediveliger					
23-25	0,207	$1,26 \cdot 10^{-3}$	$1,31 \cdot 10^{-4}$	$1,56 \cdot 10^{-3}$	$1,86 \cdot 10^{-3}$
26-28	0,233	$1,77 \cdot 10^{-3}$	$1,76 \cdot 10^{-4}$	$1,96 \cdot 10^{-3}$	$2,19 \cdot 10^{-3}$
29-31	0,262	$2,50 \cdot 10^{-3}$	$2,57 \cdot 10^{-4}$	$2,46 \cdot 10^{-3}$	$3,02 \cdot 10^{-3}$
32-34	0,294	$3,49 \cdot 10^{-3}$	$3,56 \cdot 10^{-4}$	$3,09 \cdot 10^{-3}$	$2,82 \cdot 10^{-3}$
Spat					
35-37	0,331	$4,92 \cdot 10^{-3}$	$4,86 \cdot 10^{-4}$	$3,88 \cdot 10^{-3}$	$4,65 \cdot 10^{-3}$
38-40	0,372	$6,90 \cdot 10^{-3}$	$7,02 \cdot 10^{-4}$	$4,85 \cdot 10^{-3}$	$6,17 \cdot 10^{-3}$
41-43	0,418	$9,69 \cdot 10^{-3}$	$9,99 \cdot 10^{-4}$	$6,09 \cdot 10^{-3}$	$7,88 \cdot 10^{-3}$
44-46	0,470	$1,37 \cdot 10^{-2}$	$1,40 \cdot 10^{-3}$	$7,68 \cdot 10^{-3}$	$8,69 \cdot 10^{-3}$
47-49	0,528	$1,91 \cdot 10^{-2}$	$1,94 \cdot 10^{-3}$	$9,57 \cdot 10^{-3}$	$1,28 \cdot 10^{-2}$
50-52	0,593	$2,68 \cdot 10^{-2}$	$2,70 \cdot 10^{-3}$	$1,20 \cdot 10^{-2}$	$1,63 \cdot 10^{-2}$
53-55	0,667	$3,77 \cdot 10^{-2}$	$3,78 \cdot 10^{-3}$	$1,51 \cdot 10^{-2}$	$2,10 \cdot 10^{-2}$
56-58	0,750	$5,29 \cdot 10^{-2}$	$5,40 \cdot 10^{-3}$	$1,87 \cdot 10^{-2}$	$2,68 \cdot 10^{-2}$
59-61	0,843	$7,42 \cdot 10^{-2}$	$7,46 \cdot 10^{-3}$	$2,37 \cdot 10^{-2}$	$3,46 \cdot 10^{-2}$
62-64	0,947	$1,04 \cdot 10^{-1}$	$1,06 \cdot 10^{-2}$	$2,97 \cdot 10^{-2}$	$4,48 \cdot 10^{-2}$
65-67	1,065	$1,47 \cdot 10^{-1}$	$1,49 \cdot 10^{-2}$	$3,72 \cdot 10^{-2}$	$5,79 \cdot 10^{-2}$
68-70	1,197	$2,05 \cdot 10^{-1}$	$2,07 \cdot 10^{-2}$	$4,66 \cdot 10^{-2}$	$7,48 \cdot 10^{-2}$

Some cultivation standards. The highest possible density of stocking larvae is obviously determined by the following factors: 1) the upper threshold concentration of feed, at which the latter suffices to the next supply and the efficiency of assimilation does not diminish because of the formation of pseudofeces or the clogging of the filtering apparatus. As we have found with the larvae of Ostrea edulis, this concentration does not exceed $(150-200) \cdot 10^3 \text{ cells} \cdot \text{ml}^{-1}$ for small (1-3 μm) microalgae, and $(5-10) \cdot 10^3 \text{ cells} \cdot \text{ml}^{-1}$ for large ones (10-14 μm) (Walne, 1979); 2) the available supply of oxygen, which can be removed from the water without causing any harm (30% removal usually allowed); 3) the content of toxic metabolites in the water. It can be easily calculated that with a P. lutheri concentration of $150 \cdot 10^3 \text{ cells} \cdot \text{ml}^{-1}$, which is freshened daily or, better still, maintained constantly, not more than five early veligers consuming $3.71 \cdot 10^{-4} \text{ cal} \cdot \text{day}^{-1} \cdot \text{specimen}^{-1}$ ($33.7 \cdot 10^3 \text{ cells}$) should be present in this volume of water. At the same time, the water will be filtered only once with this density, since each veliger will pass about 0.24 ml of water through itself and remove the suspension from it

$$(F = \frac{3.71 \cdot 10^{-4} \text{ cal} \cdot \text{day}^{-1} \cdot \text{specimen}^{-1}}{1.52 \text{ cal} \cdot \text{l}^{-1}}).$$

We also estimated that each specimen of one-month-old spat should be allowed 4 ml of water. As for the second condition, veliger larvae can remove 30% of the oxygen, i.e. $0.3 \cdot 8.6 \cdot 10^{-3} \text{ mgO}_2 = 2.6 \cdot 10^{-3}$, from each millilitre of seawater in 24 hours at a temperature of 15°C and salinity of 33‰; up to 27 larvae can be present in 1 ml when $Q = 3.22 \cdot 10^{-4} \text{ cal} \cdot \text{day}^{-1} \cdot \text{specimen}^{-1} = 0.94 \cdot 10^{-4} \text{ mgO}_2 \text{ specimen}^{-1} \cdot \text{day}^{-1}$. Such a high density is hardly ever used,

if only because of feed limitations. If the water is changed daily and aerated as well, there will be no shortage of oxygen. As for metabolites, our own observations have shown that the concentration of ammonium even in dense larval cultures of the Yezo scallop was much lower than the maximal allowable concentration (MAC) for the larvae of intertebrates, which is equal to $10 \text{ mg} \cdot \text{l}^{-1}$ (Epifanio et al., 1975); it amounted to only $10\text{--}15 \text{ } \mu\text{g} \cdot \text{l}^{-1}$. The standards derived by us are given in table 3.

Table 3. Some standards of cultivation of P. yessoensis larvae with a yield of one million spat

Stage	Age, days	No. of larvae, '000'000 spec/%	Density spec/ml ¹	Volume of water addition of food,kl	Daily addition of food,kl	Flowage, %
Fertilized egg cell	0	50 / 100	200	250		100
Trochophore	1,4	37 / 74	50	740		"
Veliger	2	34 / 68	5	6800	$11,5 \cdot 10^{11}$	"
	4	25,5/51	4	6400	$8,6 \cdot 10^{11}$	"
Veliconch	12-14	11,0/22	1,6	6880	$9,3 \cdot 10^{11}$	$18,7 \cdot 10^9$ "
Spat	30	1,0/2	0,25	4000	$2,7 \cdot 10^{11}$	$5,6 \cdot 10^9$ "

Discussion of results. Development and growth. According to our data, the larval development of the Yezo scallop lasted 30 days (15°C); the larvae settled on the plastic collectors when they attained a size of $240\text{--}250 \text{ } \mu\text{m}$, which corresponds with the results of Yamamoto's observations (1966). According to Ogawa et al., after Sanders, 1973), larval development lasted only 19 days and the larvae settled after attaining a larger size ($295 \text{ } \mu\text{m}$) at a temperature of 17°C ; as in our own experiments, the highest mortality was noted during spatfall and the formation of the veliconch, but Ogawa notes a higher survival rate. Of the one

million A-shaped larvae, almost one-half reached the spat stage (290 μm); approximately 30% of this spat survived at a size of about 1 mm. Consequently, the total yield amounted to 6%, probably 4-5% of all the fertilized egg cells.

The exponential nature of larval and spat growth in the Yezo scallop (growth at a constant specific rate) is common for the early stages of ontogenesis in the most diverse animals, e.g. insects (Vinberg, 1966), rotifers, sea urchins (Bregman, 1968, 1971). However, a different situation is observed in the larvae of Crassostrea gigas. The growth constant increased at first ($C_g=0.03-0.09$), remained at a very high level at the age of 5-14 days ($C_g=0.9-0.11$), and then decreased sharply during spatfall ($C_g=0.04-0.06$); at the same time, the inadequacy of the feed did not alter the nature of larval growth, but it did curtail the period of intensive growth and increased the overall length of larval development (Gerdes, 1983a). This pattern of growth is (20) probably specific to littoral organisms which pass through the most vulnerable ontogenetic stages in the unstable conditions of the littoral zone at the quickest rate.

After spatfall, the rate of larval growth increased more than 1.5-fold [see equations (2) and (3)]; an increase in growth was also noted by Ogawa et al. (according to their data, the size of the spat increased from 300 to 900 μm), as well as by Rose and coauthors for Chlamys asperimus (Rose et al., 1984). This is quite natural, since scallop larvae are active swimmers, and probably expend much of the assimilated energy on active metabolism (see table 2). As the larvae grow larger and become less active,

the portion of the energy spent on growth steadily increases, and amounts to 30% in 70-day-old spat.

The growth and survival rates obtained by us for the larvae and spat of the Yezo scallop proved to be comparatively low. The inadequacy of the feed, a shortage of it and partly a low water temperature were probably the cause of this. Indeed, the water temperature in Ogawa's experiments was 2-3° higher, food was supplied twice a day, and the density of stocking did not exceed one specimen per ml; the feed consisted of a mixture of P. lutheri and the highly recommended (Walne, 1979) small diatom Chaetoceros calcitrans, the absence of which slowed the growth of spat (up to 900 µm) considerably and increased the growth period by ten days. On the other hand, according to the data of table 2, the feed was supposed to have been eaten up completely before more was given, and so the requirements of the larvae and spat were to some extent filled by food particles of natural origin, which apparently could not provide high rates of growth and survival.

Energy metabolism and nutrition. The rate of oxygen consumption by the larvae and spat of P. yessoensis is exponentially dependent on body mass with the exponent "b" approximating 0.7. For comparison, formula (7) was recalculated, i.e. oxygen consumption was expressed in $\text{mlO}_2\text{h}^{-1}\cdot\text{specimen}^{-1}$, and mass in milligrams of dry tissues, suggesting that the latter constitute about 10% of the body mass. As a result,

$$Q = 0.529 \cdot 10^{-2} W^{0.667} \quad (\text{at a temperature of } 15^\circ\text{C}) \quad (10)$$

The average relationship for the larvae of Cr. gigas is (Gerdes, 1983b) $Q = 0.282 \cdot 10^{-2} W^{0.96} \quad (\text{at } 25^\circ\text{C}) \quad (11)$

As the larvae and spat of P. yessoensis developed, the rations and the rate of filtration at an average feed concentration of $1.52 \text{ cal} \cdot \text{l}^{-1}$ increased (as is usually the case in filter-feeders) as an exponential function of body mass [see equations (8) and (9)]. For comparison, we can say that the filtration in the developing oyster larvae (according to Gerdes) also increased, at first slowly from 0.5 to $3.6 \mu\text{l} \cdot \text{h}^{-1} \cdot \text{specimen}^{-1}$ up to the age of 7 days (90-120 μm), and then very rapidly from 13.8 to $100 \mu\text{l} \cdot \text{h}^{-1} \cdot \text{specimen}^{-1}$ up to the time of metamorphosis (120-300 μm), but the rate of water "clarification" decreased sharply from 67 to $20 \mu\text{l} \cdot \text{h}^{-1} \cdot \text{specimen}^{-1}$ during spatfall; the rations and growth rate changed accordingly. The difference in the nature of the time dynamics of filtration in the larvae of the Yezo scallop may be due, as we have assumed, to the constancy of assimilability and the generalization of the dependence of metabolic expenditure on body mass; in fact, it is this relationship that on the whole affected the calculated rations.

The rate of water filtration by scallop larvae up to 120 μm in length varies from 9.4 to $15.2 \mu\text{l} \cdot \text{h}^{-1} \cdot \text{specimen}^{-1}$ and is higher than the rate for oyster larvae; however, it is similar to that of M. edulis veligers measuring 150 μm ($11.0 \mu\text{l} \cdot \text{h}^{-1} \cdot \text{specimen}^{-1}$, at 12°C) (Riisgard et al., 1981). Prior to the setting of all three species of larvae ($L=220-300 \mu\text{m}$), the rate of water filtration is practically the same, 93-101 $\mu\text{l} \cdot \text{h}^{-1} \cdot \text{specimen}^{-1}$, despite the difference in water temperature ($15-25^{\circ}\text{C}$). In the larvae of Ostrea edulis ($L=203-270 \mu\text{m}$), the rate of filtration is significantly lower, 10.5-20.4 $\mu\text{l} \cdot \text{h}^{-1} \cdot \text{specimen}^{-1}$ at $19-25^{\circ}\text{C}$ (Walne, 1956, 1965).

Thus, we have examined here the main biotechnological indices of the cultivation of P. yessoensis larvae (survival, length of development, growth rate, rate of feed supply, rations), which can be improved on the basis of the quantitative data presented above.

Summary

1. During the development of the Yezo scallop from the time of fertilization to the hardy stage, the highest mortality is observed during the transition from veligers to veliconchs, and at the setting stage (spatfall).

2. The linear growth of P. yessoensis larvae and spat is approximated by the equation $L = 81.1e^{0.039t}$.

(22)

The rates of metabolism and filtration in P. yessoensis larvae and spat are expressed by the equations $Q = 0.164 \cdot 10^{-2} W^{0.667}$ and $F = 0.586 \cdot 10^{-2} W^{0.707}$.

The estimated density of stocking larvae and spat per litre at a temperature of 15°C and growth rates common for natural conditions should be 4000-5000 specimens at the age of 2-4 days, 250 specimens at the age of 38-40 days, and 23 specimens at the age of 68-70 days.

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